Jamming Transition in Quasi-2D Self-Assembled Nanoparticle Monolayers

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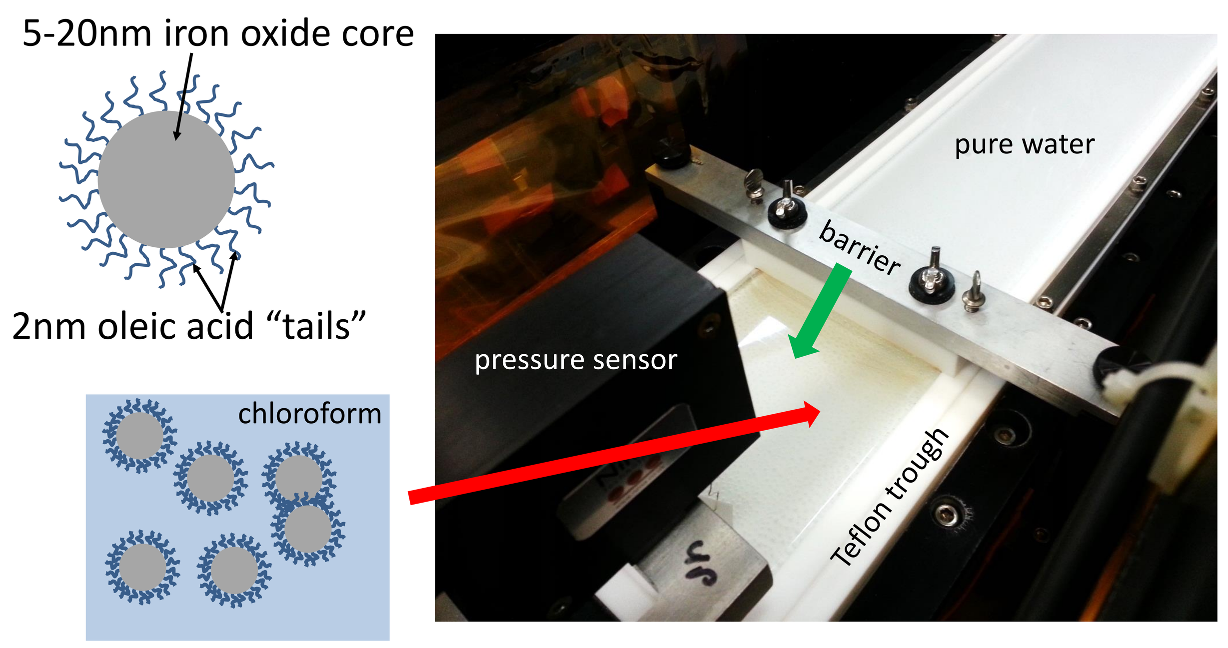
Abstract

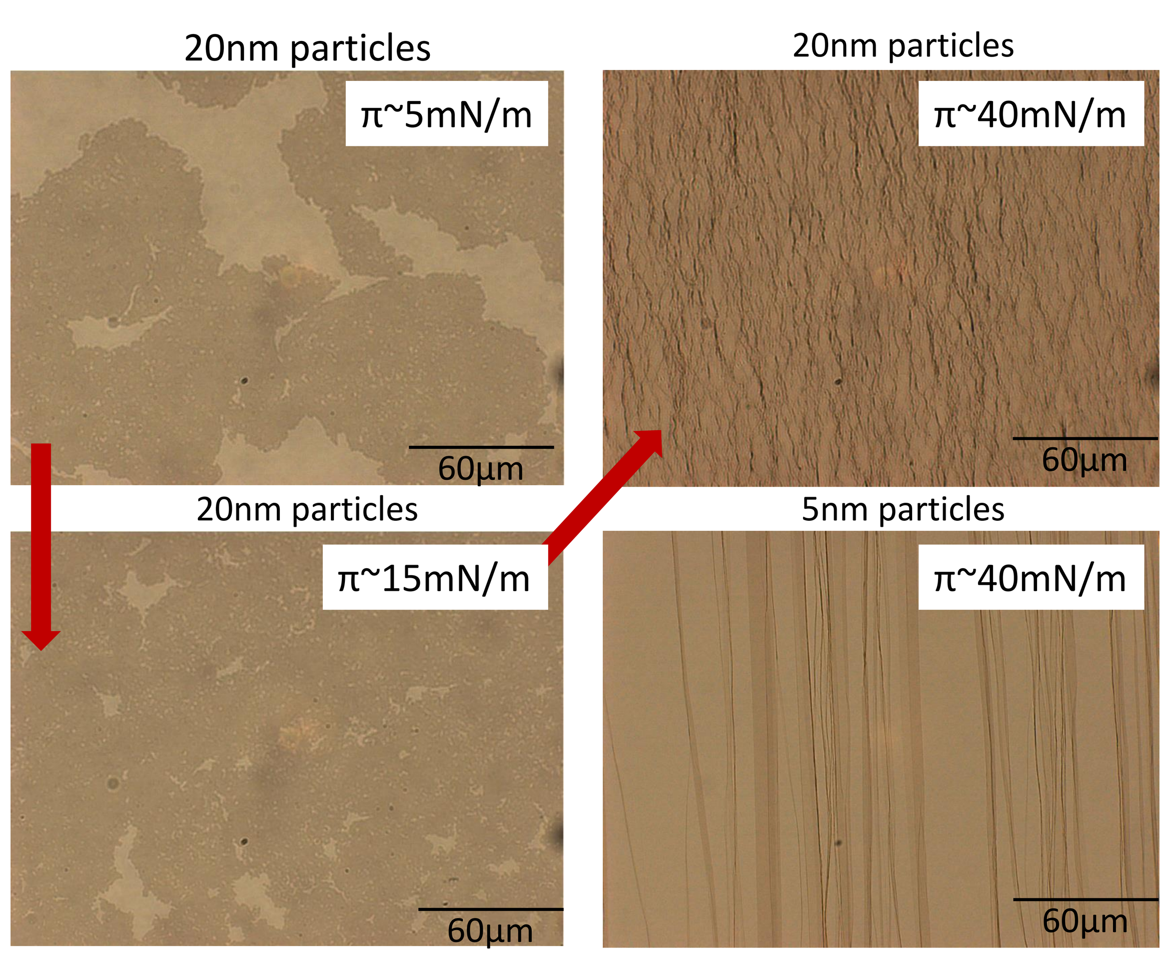
We experimentally probe the structure and interparticle dynamics of iron oxide nanoparticle thin films self-assembled at the liquid-air interface. Utilizing X-Ray Photon Correlation Spectroscopy (XPCS) at beamline 8-ID-I of the Advanced Photon Source at Argonne National Lab, we have measured the characteristic timescale of in-plane interparticle dynamics. We have found a jamming exponent of 1.5, a value that has previously only been observed in 3D aging soft matter systems.

Self-Assembly at the Water-Air Interface



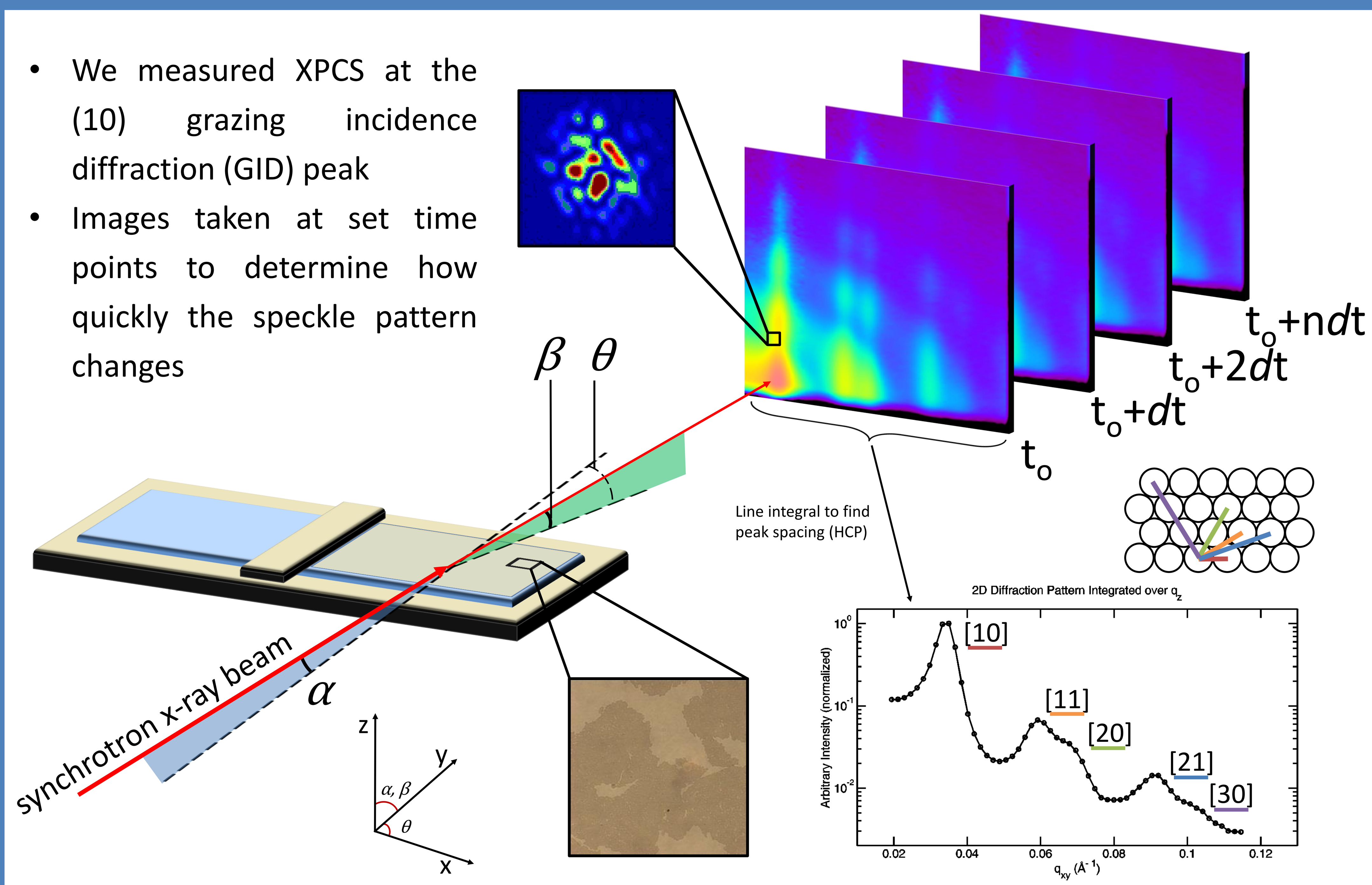
- Hydrophobic tails buoy particles on liquid surface
- Van der Waals and interfacial forces cluster particles
- Particles self-assemble into HCP configuration

Film Morphology Under Compression



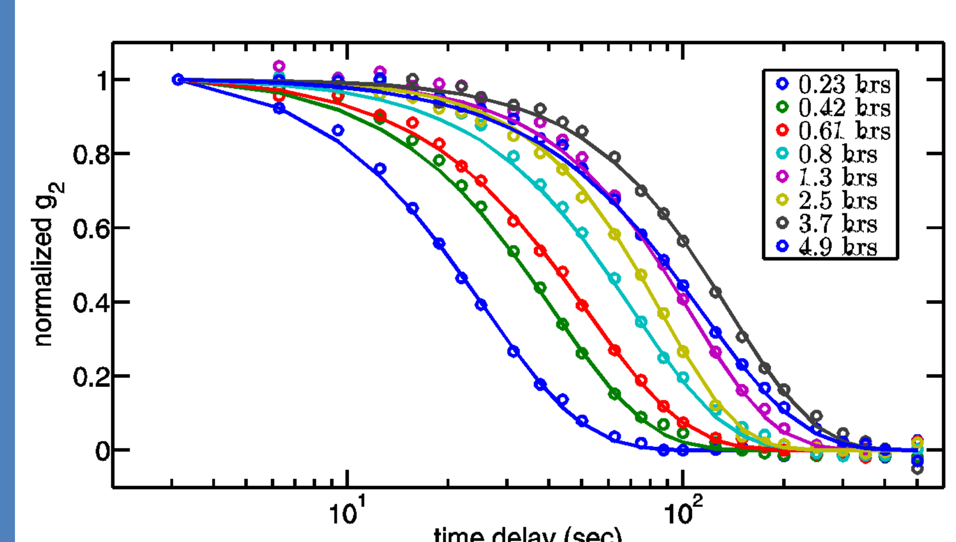
X-Ray Photon Correlation Spectroscopy (XPCS)

- We measured XPCS at the (10) grazing incidence diffraction (GID) peak
- Images taken at set time points to determine how quickly the speckle pattern changes



XPCS Analysis

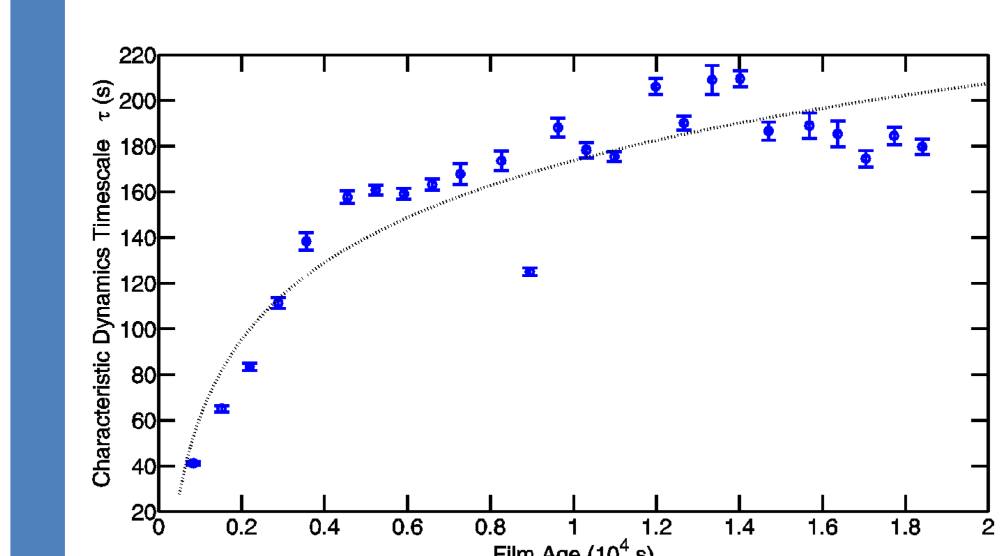
$$g_2(\Delta t) = \frac{\langle I(t)I(t+\Delta t)\rangle_t}{\langle I(t)\rangle_t^{\,2}}$$

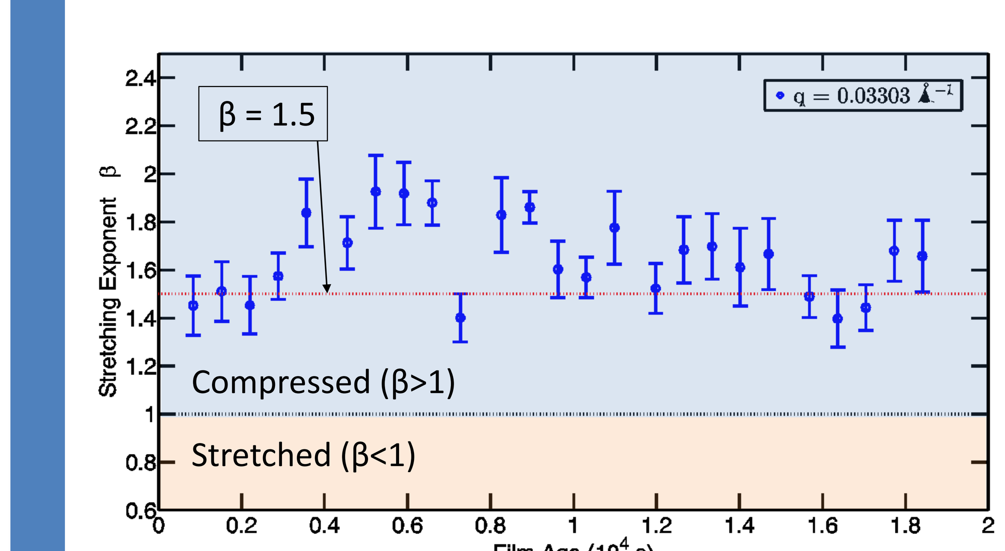


Type of system

$$g_2 \propto e^{-\left(\frac{t}{\tau}\right)^{\beta}} \begin{cases} \beta < 1 & \text{glassy} \\ \beta = 1 & \text{Brownian} \\ \beta > 1 & \text{jammed} \end{cases}$$

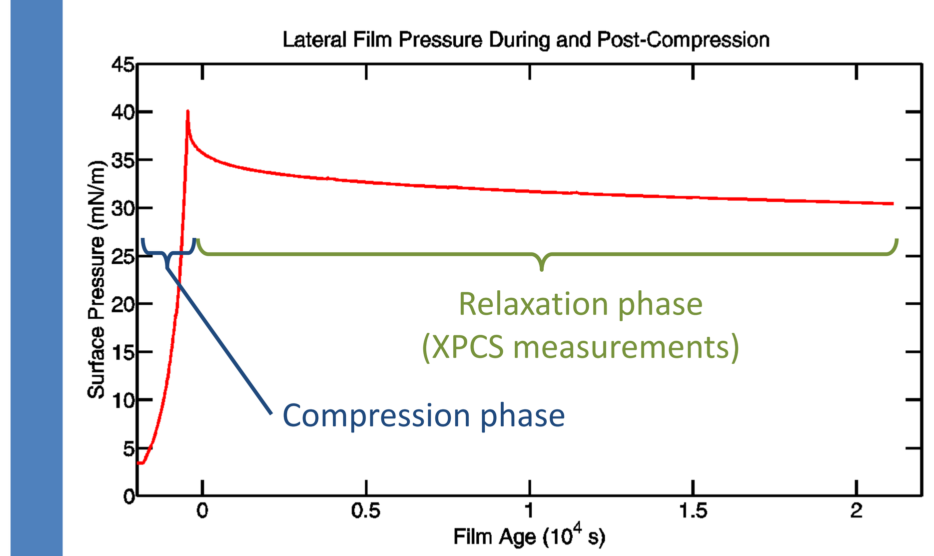
Timescale Analysis

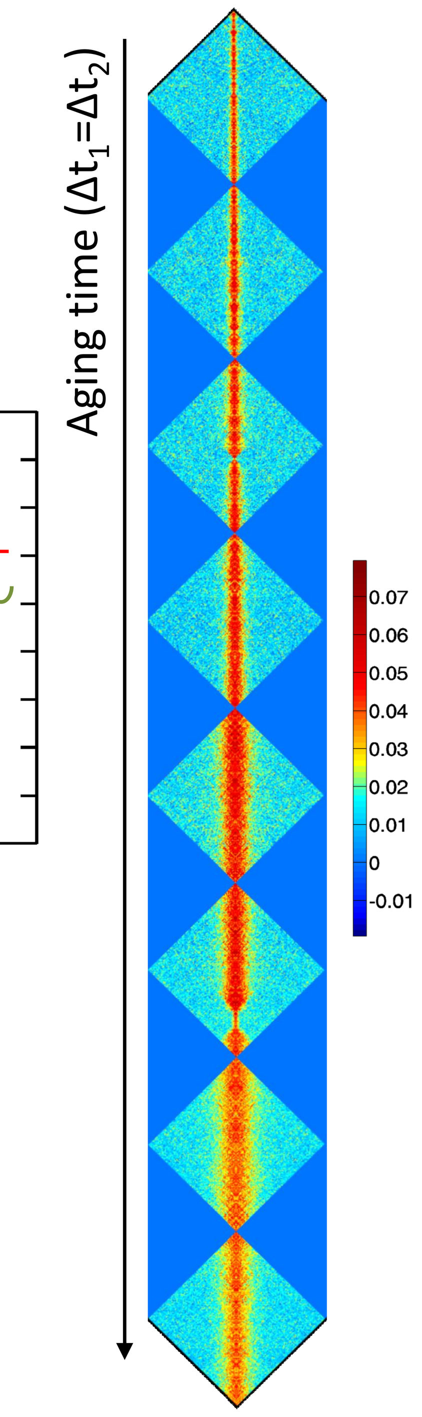




Two-Time Correlation

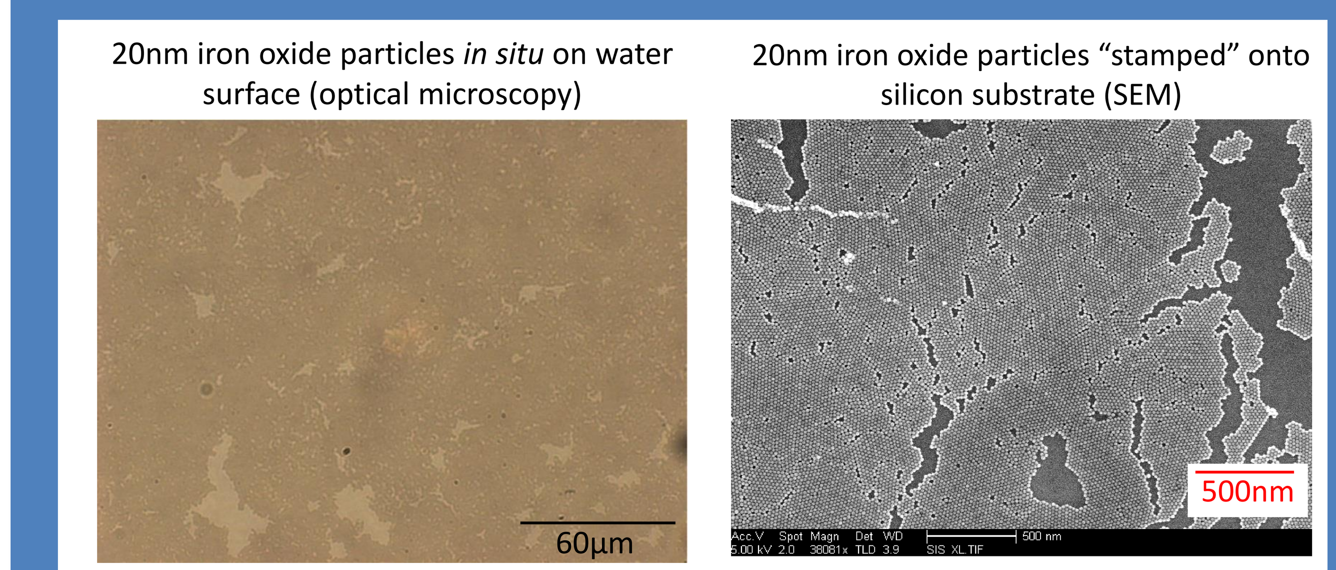
$$g_{2-time}(\Delta t_1, \Delta t_2) = \frac{\langle I(t+\Delta t_1)I(t+\Delta t_2)\rangle_t}{\langle I(t)\rangle^2}$$





- Width of the high intensity region corresponds to dynamics timescale
- "Pinched" regions correspond to avalanche events common to jammed systems

Structural Self-Similarity



Conclusion

- Compressed exponent β = 1.5 common to many aging soft matter systems* and has widely been attributed to dimensionality
- This same exponent is found in our quasi-2D system, perhaps showing a greater universality

* Bandyopadhyay, R., *et. al.* (2004). Evolution of Particle-Scale Dynamics in an Aging Clay Suspension. *Physical Review Letters*, *93*(22), 228302.
Bouchaud, J.-P., & Pitard, E. (2001). Anomalous dynamical light scattering in soft glassy gels. *The European Physical Journal E*, *6*, 231–236.
Cipelletti, L., *et. al.* (2003). Universal non-diffusive slow dynamics in aging soft matter. *Faraday Discussions*, *123*, 237–251.